

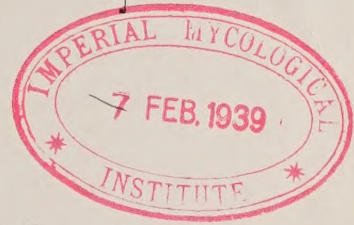
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BULLETIN No. 683

SEPTEMBER, 1938

New York State Agricultural Experiment Station

Geneva, N. Y.



COMBATING DAMPING-OFF

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PUBLISHED BY THE STATION
UNDER AUTHORITY OF CORNELL UNIVERSITY

ABSTRACT

THIS paper summarizes 9 years of work on damping-off and its control by seed protection and soil treatments. High soil moisture seems to enhance pre-emergence damping-off more than low soil temperature.

Seed protectants are given considerable attention. Usually seed protectants carry seeds thru periods of sub-germination temperatures in the soil, but the lima bean seems to be an exception. The differential action of zinc oxide and red cuprous oxide as seed protectants appears to be chiefly a question of differential injury.

Inoculum potential (disease-producing power of the soil) was investigated in relation to seed protection. Inoculum potential was measured by determining the percentage of decay of non-protected seeds. Seed protection with red cuprous oxide and copper sulfate did not diminish greatly with increasing inoculum potential until the latter reached about 80 per cent of maximum. Above that point, protective value fell off rapidly with increasing inoculum potential.

From dosage calculations it appears that about 0.5 mg of metallic copper (as cuprous oxide) per square centimeter of seed surface is required to give minimum coverage dosage on seeds. Apparently, this is not affected by the kind of seed.

Retention of the material on the seed and the proportion of active agent in the compound are shown to be important in seed protectants.

The role of soil treatments in damping-off control is discussed rather fully. It is suggested that low-temperature pasteurization of soil can be made more efficient by improving machinery so that soil is moved past the heat source. At present heat is allowed to move by conduction thru the soil.

It is suggested that seedlings be sprayed with a no-lime copper fungicide such as red copper oxide or copper oxychloride to prevent spread of post-emergence damping-off thru the soil surface. Dribbling such chemicals as formalin and copper sulfate solutions into the soil along with the seed is shown to be worthy of trial to control pre-emergence damping-off in the field.

A final section of the paper is devoted to practical suggestions for disease control.

COMBATING DAMPING-OFF

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THE SIGNIFICANCE OF DAMPING-OFF

DAMPING-OFF is a specter that may confront any plant grower at the most inopportune moment. Unchecked, it may nullify an evening's work for the window box gardener, demolish a few days' work for a pea grower, or beat down all the seedlings transplanted in a week by a dozen women in a large greenhouse.

An instance came to hand as recently as two years ago when the disease stalked in and flattened 200,000 transplanted tomato seedlings for a single grower who would have been ready in a few days to sell them on contract for five dollars per thousand.

Damping-off is a destructive disease. Damping-off control is a preventive measure. Damping-off control assures the gardener of the crop that he plants. Damping-off control is not a device for making two plants grow where only one grew before. It simply is an insurance measure to protect what the grower already possesses.

For 15 years this Station has been hammering at the damping-off problem intensively, beginning with the introduction of the corrosive sublimate treatment for seedlings by Gloyer and Glasgow (16)² in 1924. Even as early as 1901, however, Stewart collaborated with Duggar (11) in proving for the first time that *Rhizoctonia* can parasitize plants.

During the twenties the work of Gloyer and Glasgow was followed by that of Clayton (6,7) and Jones (31,32). During the thirties the writer has investigated damping-off extensively.

Since almost all of the Station's publications on damping-off are now out of print, this bulletin has been prepared to bring all information on damping-off control up to date and to add other results not heretofore published.

¹The writer acknowledges with thanks the assistance of Doctors A. L. Harrison, R. O. Magie, and R. F. Suit during parts of this research.

²Refers to Literature Cited, page 43.

HOW DAMPING-OFF ATTACKS

It is the suddenness of damping-off attack that impresses most observers. One day seedlings look well, the next they are down in big, mangy patches over the seedbed. Unfortunately, however, that symptom, distressing as it may be to the owner, is not the only destructive aspect of damping-off.

THE SYMPTOMS

Pre-emergence damping-off. A common and perhaps the most serious aspect of the disease is not even associated with it in the lay mind. That phase is pre-emergence damping-off, the attack of the disease before the tiny seedling can push thru to the surface of the soil. Only too often poor stands of crops both in greenhouse and field are caused by attacks of damping-off on germinating seeds. A plant is just as tender and succulent and susceptible to damping-off, if not more so, before it emerges from the ground as afterward. That is why, when good seeds fail to come up well, they are erroneously considered inferior. After the seedling once gets up into the sunlight, it rapidly gains resistance to damping-off.

Post-emergence damping-off.—The usual symptom observed occurs after the emergence of the plant above ground. The stem of the individual plant may become water-soaked at the ground line and fall over, usually even before the leaves can wilt. Sometimes leaves on diseased plants turn darker green than healthy plants. At other times brown lesions occur on the stems and tap roots, the stems become girdled, and the plant falls over. Having gained a foothold on a single plant, the disease spreads in widening circles as long as conditions permit. When several isolated spots start together in a greenhouse, one gets the impression that the stand of plants is pockmarked, moth-eaten, or mangy. A more complete discussion of the two phases of damping-off is presented in Technical Bulletin No. 198 of this Station.

Symptoms of damping-off need little discussion, however. The malady cannot be confused with any other trouble. Of more importance in understanding the disease and in appraising methods of control is to clarify the cause of the trouble.

CAUSE OF DAMPING-OFF

Fungi.—A widespread notion prevails that damping-off is due to excessive soil wetness, altho some growers maintain stoutly that they have checked it with applications of water. Damping-off fundamentally

is the result of the activities of microbes, which may readily be seen by examining diseased roots with a microscope.

These organisms responsible for damping-off may come from two sources, *viz.* (a) they may be carried into the soil on the seed, with the seed, or in the seed; or (b) they may live in the soil. This distinction is of some importance in understanding control measures. Seed-borne organisms are eliminated by various seed disinfectants. Soil-borne organisms are controlled (a) by killing them outright as in cooking the soil or (b) by protecting the seed or the seedling against attack with chemicals on the seed or the soil.

In New York State the soil fungus principally involved is *Pythium ultimum* Trow, a water mold. Another one sometimes involved is *Rhizoctonia solani* Kuhn, the fungus causing the black scabs on potato tubers. Occasionally *Botrytis cinerea*, *Phytophthora sp.* and other fungi cause some damping-off.

Altho soil fungi are chiefly responsible for the disease, it must be said that damping-off is influenced by the weather.

Soil wetness.—As implied by its common name, dampness is very important in an attack by damping-off. This weather factor is so important that many growers who do not have a microscope believe that the excessive wetness is the only cause of the disease. It would be more accurate, however, to state that the wetness favors the water mold, *Pythium*, that is fundamentally the cause of the trouble. It is necessary to have this distinction clearly in mind before proceeding to the control of the disease. If the wetness only were involved, the only possible control, of course, would be to control the watering hose and ventilation. Certain soil and seed treatments, however, will give excellent control, irrespective of moisture. The answer is that these treatments kill off the guilty fungus so that it can no longer attack the plants.

Excessive salt concentration in soil.—To state a paradox, there are records of damping-off in New York that are not damping-off in the usual sense of the term. The cases look superficially like damping-off, but the symptoms are somewhat different.

In slight cases the only symptom is a browning of roots. In aggravated cases the plants die and fall down as if they were damped-off. An expression of some growers that they are burned-off is perhaps a better characterization. The root and most of the seedling stem shrivels with a dry brown rot. The line of separation between diseased and living tissue is not sharp as in the case of ordinary damping-off. The disease

cannot be controlled with means usually employed—such as seed protection and seedling sprays as discussed below. In fact such measures aggravate the trouble, if anything. In one set of cold frames it was strikingly demonstrated that this type of trouble was corrected by drips from the glass, not aggravated as is the case with ordinary damping-off. A symptom always associated with the malady is an uneven growth of seedlings or transplants that are not killed. Small areas in the flats may be taller and greener than the rest or shorter and more purple than the rest. In fact the purpling seems almost always associated with it.

Since this aspect of damping-off has only recently been recognized as such, its description may not be complete or wholly accurate, but it will serve to emphasize the point that all damping-off may not be the old-fashioned one caused by microbes aggravated by wet soil.

The plants die and shrivel from thirst in the midst of plentiful water because the water available contains so much salt that the plant cannot use it. The salts (not table salt, of course) in the soil make the water so concentrated that the plant cannot get enough to live on, hence, it shrivels and dies.

The manner in which the soil water gets so heavily saturated with these salts varies. Probably all the ways are not yet clear. If the soil lies a long time dry in the greenhouse, the soluble materials formed by chemical processes cannot be leached out by rains. If the compost heap is built from dust dry soil in the summer and so shaped on top that water cannot run into the pile, soluble salts will accumulate because they are not leached out.

In some cases the trouble seems due to too much fertilizer or manure added to the soil. In other cases it seems almost certain that bone meal, especially steamed bone meal, will aggravate the trouble. In fact the three most serious cases so far studied were associated with bone meal in the soil.

The effect of soil type is not clear, but all cases so far on record occurred near Lake Erie or Lake Ontario on the sandier soil types.

The weather conditions that influence it are not clear, but apparently it gets a start during hot periods, altho it may not show up until a day or two later.

The alleged control of damping-off by excess watering is obviously a control of this phase of the trouble by leaching out the salts. Many growers report that they can take the purple color out of tomatoes by a heavy watering. That, of course, dilutes the soil solution, even if it does not leach any salts out.

Growers report best results in damping-off control by heavy watering at long intervals rather than frequent sprinklings. Part of this is due to some discouragement of the fungus causing ordinary damping-off, altho the excess water when applied should give it a good opportunity to attack the seedlings. Some of the beneficial effects reported may also be due to a lowering of the concentration of salts that build up.

THE RÔLE OF SEED DISINFECTION

The methods for controlling damping-off will be presented under three headings, seed disinfection, seed protection, and soil treatments.

Some damping-off fungi ride into the soil on the seeds. For example, the seedling blight fungus, *Gibberella saubinetii*, finds its way into the soil on seeds of corn, wheat, and other cereals. An organic mercury, such as Semesan Jr., on corn kills such organisms and reduces damping-off of the seedlings.

Alternaria solani is carried into the soil on tomato seeds where it may produce damping-off, foot rot, or collar rot. Much of this fungus can be killed by soaking tomato seeds in corrosive sublimate 1-2,000 for 5 minutes, followed by a rinse in clean water.

There are many other examples of damping-off control which depend upon killing the fungus on the seed. On the other hand, many seed disinfectants, in fact most of them, show little effect on damping-off as, for example, the hot water treatment of wheat for loose smut. Even the corrosive sublimate treatment on tomatoes has little or no effect on soil-borne damping-off (22).

THE RÔLE OF SEED PROTECTION

Most damping-off fungi, such as *Pythium ultimum* and *Rhizoctonia solani*, do not ride into the soil on the seeds. They are normally resident in the soil. Finnell (14) and then Clayton (6) were probably the first to recognize clearly that seeds that had been disinfected with organic mercury materials were protected at the same time against the attack of soil organisms causing pre-emergence damping-off.

The theory of seed protection is now fairly well recognized and is widely used as a practical method of damping-off control in both greenhouse and field, particularly in the field where other methods of control are not readily adaptable. It should be stated at the outset that seed protection finds its chief value in combating pre-emergence damping-off. It will give marked reduction of post-emergence disease

before the first transplanting and is relied on exclusively by some growers who are not excessively worried by the disease. In serious attacks, however, seed protection should be supplemented.

COPPER SULFATE SOAK

The rôle of copper compounds as seed protectants has been investigated extensively at this Station. The impetus to study seed protection came in 1929 when two greenhouse operators inquired if soaking tomato seeds in copper sulfate would control damping-off. Such an effect had not been reported in the literature, but it was investigated (20). The soak treatment is still widely used especially for tomatoes and spinach, the seeds being soaked for a few minutes in bluestone solution, 1 pound in 8 gallons of water. No rinsing is required. The treatment is particularly adapted to tomatoes to follow the corrosive sublimate treatment when the seeds are already wet. Seeds may be sown wet or dried and sown later. The original two flats of tomatoes showing the protective effect of copper sulfate are illustrated in Fig. 1.

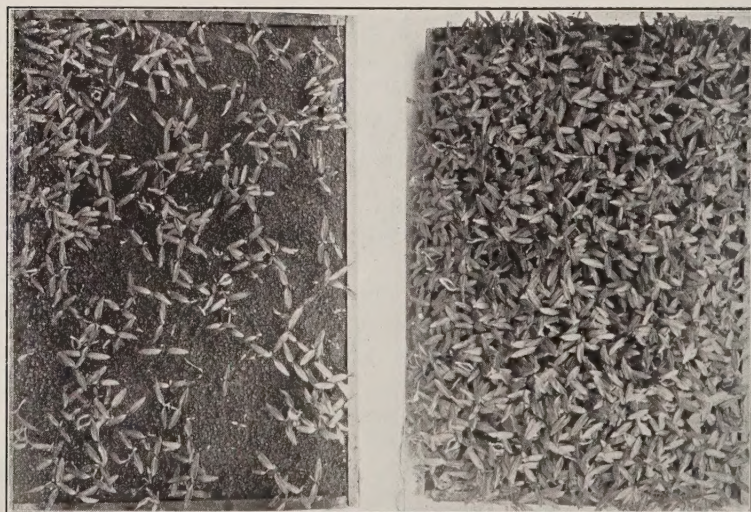


FIG. 1.—PROTECTIVE EFFECT OF COPPER SULFATE SOAK ON TOMATO SEEDS.
Left, 1,900 unprotected seeds; *right*, 1,900 protected seeds.

COPPER SULFATE MONOHYDRATE DUST

As soon as the value of the bluestone soak was established, a search for a suitable dust began. Because it is easy to purchase, copper sulfate monohydrate was suggested (22) in 1932. It did not adhere well to smooth seeds, and being soluble, produced considerable injury in sandy or acid soils. It has almost disappeared from use as a seed protectant. In the meantime a more suitable material, red copper oxide, was found and reported on (23) late in 1932.

RED COPPER OXIDE

Red copper oxide was much more dustable than the monohydrate, was retained better on the seeds, and was not as injurious to seeds. As a result it has maintained for itself a place as a seed protectant. The first results on the copper seed protectants were obtained in the greenhouse. Pirone, *et al.* (39) showed that the method was also suitable in the field on spinach seeds. In fact, it is now known that spinach responds probably better to red copper oxide treatment than any other plant.

Plants benefited.—As soon as red copper oxide was adopted by growers, they wondered which seeds could and which could not be treated with it. This subject was considered at length by Horsfall, Newhall, and Guterman (26) who tested 107 species and varieties of plants. From their results and from reports from reputable greenhouse men, it is clear that the following plants may be benefited by red copper oxide treatment: Arabis, arbor vitae, azalea, beet, calceolaria, calendula, carrot, centaurea, chard, cobaea, cockscomb, coleus, columbine, cosmos, cucumber, dahlia, didiscus, digitalis, eggplant, escholtzia, endive, geum, gilia, gypsophila, helichrysum, heliopsis, lettuce, lupine, marigold, *Mesembryanthemum tricolor*, muskmelon, nasturtium, nemesia, pansy, pea, penstemon, pepper, phacelia, phlox, pine, primula, pyrethrum, rhododendron, scabiosa, salpiglossis, snapdragon, spinach, squash, stock, sugar beet, tomato, venidium, verbena, viola, and zinnia.

This list, long as it is, makes no attempt at completeness. It may be that plants listed here would show injury under some conditions and it may be that dozens of others not listed would respond favorably.

Plants injured.—The most notable of the plants injured by red copper oxide are the members of the cabbage family—broccoli, cabbage, cauliflower, kohlrabi, radish, turnip, altho many of these respond favorably in sweet soil such as those near Geneva. Other plants that

should be treated with caution if at all are agrostemma, apple, asters, aubrietia, chrysanthemum, clarkia, dianthus (all species), dimorphotheca, gaillardia, hibiscus, hollyhock, larkspur, and petunia. Two other generalizations that seem sound are that members of the Compositae and Malvaceae seem to be liable to injury, altho favorable responses have been observed in both groups.

Possibilities not tested adequately.—Notably absent from the lists of plants benefited and injured are the cereals, forest seeds, except pine, and forage crops. These are excluded because they have not been tested, altho Koehler (34) recently reported that red copper oxide was one of the best protectants on corn seed. It was superior to the mercury compounds for that purpose, but was less effective than the mercuries on Diplodia-infected seed. Since forest seedlings damp-off badly, red copper oxide should be tried on them. The same is true of forage crops like alfalfa and clover. Preliminary trials (24) on these as mentioned below where zinc oxide is discussed (page 17) show that they will probably respond favorably.

Apparent stimulation.—The so-called stimulation of seedlings by seed protectants is still a moot question, altho considerable data have been accumulated on the subject. Acceleration of emergence, as shown in Fig. 2 for squash, is a common observation. It has been erroneously objected that this is a delusion, that only more seedlings have appeared on the treated areas. Later the treated seedlings may seem to grow

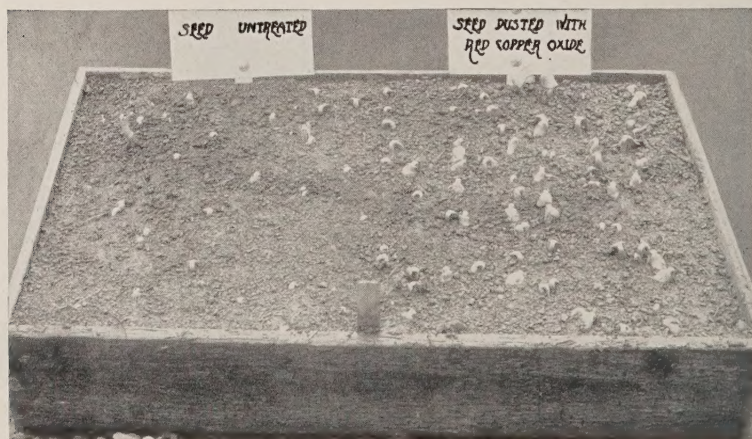


FIG. 2.—ACCELERATED EMERGENCE OF SQUASH SEEDLINGS FROM SEEDS PROTECTED WITH RED COPPER OXIDE.

taller than non-treated as shown in Fig. 3 for tomatoes. Likewise it may be objected that thick stands prevent the individuals from sprawling so that the seedlings look taller. Data already published (26) indicate



FIG 3.—ACCELERATED GROWTH OF TOMATO SEEDLINGS FROM SEED PROTECTED WITH COPPER SULFATE MONOHYDRATE.

each objection may be valid at times, but nevertheless upon careful testing in natural soil it is observed that seedlings from protected seeds do grow more rapidly than otherwise. Clayton, (7) has observed the same effect. One of his pictures is reprinted in Fig. 4 to show a stimulating effect of treating string bean seed with copper materials.



Photograph by courtesy of E. E. Clayton.

FIG. 4.—ACCELERATED GROWTH OF STRING BEANS FROM SEED PROTECTED WITH COPPER TARTRATE (CENTER) AND COPPER ACETATE (RIGHT) AS COMPARED WITH NON-PROTECTED SEED (LEFT).

In this connection it is still objected that the effect is not stimulation *per se*, but protection against soil organisms. Experiments (22) show that copper-protected seeds sprout and grow more slowly in steamed soil than non-copper-protected seeds. This seems to prove that if the organisms are killed by heat the protective effect is no longer apparent and the stimulating effect disappears. On the other hand, steaming soil injures most seedlings and it may injure treated seedlings more than non-treated. In the case of Clayton's beans (Fig. 4) the difference in stand was negligible.

Peas afford some evidence that the protective effect is important, nevertheless. The pea seed remains below ground and sometimes rots early, thus permitting root rotting organisms to enter. Red copper oxide keeps the seed intact longer than otherwise so that the seedling can obtain more nourishment and grow faster than otherwise. Kadow and Anderson (33) report a similar phenomenon.

This factor cannot be important, however, in the case of squash, spinach, and tomato where the seed is not left behind to rot.

Another "stimulating" symptom is the deepening of the green color of seedlings from copper-coated seeds. This is sometimes quite pronounced on tomatoes and spinach. Likewise, the treatment increases the red color in stems of cabbage and kohlrabi, but this seems to be associated with stunting.

Coverage capacity.—Perhaps the chief claim to value that red copper oxide has in relation to other possible seed protectants is its coverage capacity. This is because it is retained well by most seeds and because it carries a high percentage (85 per cent) of active ingredient. A good grade of it will stick to everything it touches. Different grades of red copper oxide have differing coverage capacities. Kadow and Anderson (33) emphasize the value of adequate seed coverage in control of pre-emergence damping-off by seed protection.

Effect on different fungi.—There is a feeling among some plant pathologists, difficult to trace but perhaps attributable to Wiant (43), that *Rhizoctonia solani* is not sensitive to copper fungicides. *Rhizoctonia sclerotia* have been dipped in cuprous oxide suspensions in this laboratory. When placed on agar they thrust out mycelium thru the cuprous oxide layer, indicating no inhibition from the copper. Similar treatments with mercury killed the fungus.

On the other other hand, three different writers (1, 26, 33) have shown that seeds protected with copper fungicides and sown in pasteurized soil artificially infested with *Rhizoctonia* are protected to

some degree, not well perhaps on account of high inoculum potential, but protected, nevertheless, against invasion. The brown patch disease of turf caused by *Rhizoctonia* may also be held in check by copper fungicides (35), altho they are not used in practice because copper accumulations injure the grass roots. This indicates that in soil, at least, copper is toxic to *Rhizoctonia*.

The protective effect of copper against *Pythium ultimum* is not unexpected. It has been demonstrated by Alexander, *et al.* (1), by Horsfall (23), and by Kadow and Anderson (33).

Influence of temperature and moisture on protective value.—For several years intensive research has proceeded at this Station on the problem of temperature and moisture influences on damping-off.

Two types of equipment have been used in this work. One type is a three-section greenhouse where three temperatures are available. Control is maintained by an air-operated thermostat adjusted to actuate either the steam line or a blower in the ridge of the house, depending upon whether the temperature of the house is too low or too high. The other type is a "climate laboratory", an early model of which has been described (21). The climate laboratory very briefly is a series of six chambers similar to those described by Johnson (30) placed in a refrigerated basement room. The chambers are lighted artificially. Each chamber is provided with four series of double-walled auto-irrigators with four units each. Each series operates at a different soil moisture content. Each chamber operates at a different temperature (if so desired). The six chambers and four moisture contents make possible 24 combinations of soil moisture and soil temperature.

A large number of experiments have been completed, but the data have not been fully digested yet and hence must be reserved for later publication. In general it seems that high soil moisture is a more serious limiting factor in pre-emergence damping-off than low soil temperature. Kadow and Anderson (33) agree with this finding. Apparently there is a bimodal curve for temperature, at least for peas with a minimum of emergence at about 18°C. This point has not been fixed precisely and varies with the species of plant and the soil sample.

In working on soil moisture in relation to pre-emergence damping-off of peas, Jones (32) called attention to the fact that rain immediately after seeding accelerated seed decay of peas, presumably by activating the soil organisms. The physiologists suggested that this might be due

to lack of oxygen and not to decay organisms. An experiment was set up to determine this point.

Two types of soil were used in the experiment, one a "pea sick" soil from a field where peas had failed from root-rot, the other a greenhouse loam known to contain damping-off organisms. Half of each soil was steamed in flats for $1\frac{1}{2}$ hours at 25 pounds pressure to rid it of organisms. Ten flats of the steamed soil and 10 flats of the non-steamed soil of each type were sown with 100 Perfection pea seeds each. The flats were watered in duplicate after the lapse of varying lengths of time, as shown in Table 1.

TABLE 1.—EFFECT OF TIME OF WATERING ON EMERGENCE OF PEAS FROM STEAMED AND FROM NON-STEAMED SOIL; DATA ARE AVERAGES OF EMERGENCE FROM DUPLICATE FLATS.

"PEA SICK" SOIL FROM FIELD			INFESTED GREENHOUSE SOIL		
Time between planting and watering, hours	Percentage emergence		Time between planting and watering, hours	Percentage emergence	
	Steamed soil	Non-steamed soil		Steamed soil	Non-steamed soil
0	72.0	0.0	5	58.0	3.0
7	...	6.0	24	73.0	13.0
24	37.5*	26.0	48	79.0	32.5
48	65.0	50.0	72	83.5	45.5
72	45.5*	56.5	96	81.0	63.5
Average green weight per plant, grams	1.32	1.15		1.12	1.03

*Mice destroyed seeds in these flats.

The results of the experiment with greenhouse loam are pictured in Fig. 5. Emergence from non-steamed soil increased as the length of time increased between planting and watering. Emergence from the steamed soil was essentially equal for all flats irrespective of the time of watering. The results were in agreement for both kinds of soil. Thus it is indicated that to plant ahead of a rain is to encourage pre-emergence damping-off. If there are no disease organisms in the soil, this effect does not occur. Jones has shown further that chemical seed protection will help to avoid rotting by the soil organisms even if rain does follow shortly after planting.



FIG. 5.—EFFECT OF TIME OF WATERING ON EMERGENCE OF PEA SEEDS.

Rear, soil steamed; *front*, soil not steamed. From left to right, time between planting and watering was 5, 24, 48, 72, and 96 hours, respectively.

Temperatures too low for the seed concerned to germinate are sometimes encountered in the field. Practical growers have frequently reported that red copper oxide gives protection during such a period on such crops as peas and sweet peas.

In December, 1934, 12 flats of cucumber seeds were sown in naturally infested soil, 6 with non-protected seeds, and 6 with red copper oxide-protected seeds. Two flats of each were then distributed to three greenhouse sections with temperature thermostatically controlled at 24°C, 18°C, and 12°C. The seeds came up fast at 24°C, but many non-protected seeds decayed. They came up slower at 18°C and more of the non-protected seeds decayed. The seeds refused to emerge at 12°C and were kept there in almost saturated soil for 70 days, when they were then removed to the 24° house where they immediately emerged. The significant fact was that the non-protected seeds this time came up very much better after being held all winter in wet soil at low temperatures than when placed immediately at 24°C. No explanation is available for this striking result. It is interesting that the damping-off fungi were not inactive at the 12° temperature because beets and spinach were damped-off at that temperature when planted in the same soil at the same time.

Lima beans in another experiment in the climate laboratory showed the opposite result. When placed at 15°C and 25°C, they came up rapidly at 25°C, showing slight response to red copper oxide protection. They refused to come up at 15°C. After about 21 days, the temperature was shifted to 25°C, but still they refused to come up. Examination showed that the seeds were decayed with a dry brown rot.

Specifications for red copper oxide.—When red copper oxide was first adopted as a seed protectant in 1932 and 1933, growers found much difficulty in obtaining a satisfactory grade of material. Most lots available to the trade soon oxidized to black copper oxide and became very lumpy. Such grades were known to be inferior as seed protectants. To assist the purchaser a set of tentative specifications were set up (26), the most significant of which was that samples should be bright red approximating carmine. This specification was set up to avoid oxidized cuprous oxide.

Heuberger and Horsfall (19) have just completed an investigation of the relation of color to protective value and particle size of cuprous oxide. Cuprous oxides range from a yellow color where the particles are small thru red to purple where they are quite large. The thermal method of preparation seems to superimpose a certain brown tone on the base colors.

A typical data table presented by Heuberger and Horsfall (19) is given in Table 2. With regulated dosages, it is clear that protective value decreases as the dosage decreases and it decreases as the color shifts from yellow thru red to purplish. Yellow cuprous oxide is not yet on the market, the sample being prepared experimentally. Red cuprous oxide, however, is obviously to be preferred to purple cuprous oxides.

One explanation for the varying results obtained recently by others (2) is they used an excess of material. The coarse particles in the cameo-brown (purplish) grade sifted from the seeds leaving enough small particles to be effective.

A set of specifications revised in the light of later research are given herewith:

1. The material should contain not less than 95 per cent of cuprous oxide. A measure of purity and protective value.
2. A bright brick-red color is a good guarantee of purity and protective value, altho certain darker colored materials may prove to be essentially as good if they are used in excess and screened.

Glittering particles indicate metallic copper which is essentially valueless as a seed protectant.

3. The color should not darken on standing in air. A measure of stability.
4. The material should pass dry thru a 325-mesh screen. A measure of clumping. The mean particle diameter should be approximately 8 microns or smaller.
5. If a small amount of material is placed on white paper which is then changed slowly to a vertical position, the paper should retain sufficient dust to be well colored. A measure of retention.
6. The material should flow in a bottle in a manner resembling water. It should fume or smoke when shaken in a bottle and it should not collect into lumps under these conditions. A measure of coverage capacity.

TABLE 2.—RELATION OF COLOR OF CUPROUS OXIDES TO PROTECTIVE VALUE ON PEA SEEDS

DOSAGE, PER CENT BY WEIGHT	EMERGENCE FROM 100 SEEDS					
	Greenhouse, 18° C*			Climate laboratory, 15° C†		
	Purple	Red	Yellow	Purple	Red	Yellow
0.0625	25	46	58	21	48	54
0.1250	37	56	65	44	65	78
0.2500	58	66	81	57	67	81
0.5000	60	81	87	65	73	80
1.0000	74	83	86	71	76	70

*Emergence of non-treated seed 5.

†Emergence of non-treated seed 4.

ZINC OXIDE

Zinc oxide was developed (24) primarily as a soil application as discussed below (page 31), but it was discovered at the same time to possess distinct qualities as a seed protectant, a possibility developed extensively by Cook and Callenbach (9).

Of various seeds tested at Geneva, zinc oxide seems to best adapted to the cabbage family. Zinc oxide has given good protective effects on alfalfa, beet, broccoli, brussels sprouts, cabbage, cauliflower, Chinese cabbage, clover, cucumber, eggplant, endive, kale, kohlrabi, lettuce, parsley, pepper, radish, spinach, tomato, and turnip. It has been inferior to red copper oxide on beet, eggplant and pepper. It has injured lima bean and pea. Results here, in Illinois (33), and in Virginia (10) indicate rather clearly that zinc oxide is almost, if not quite, as good as Semesan for cabbage seeds and, of course, it is very much cheaper.

It is interesting also that zinc oxide (Vasco 4) has practically replaced red copper oxide as a protectant for fall-sown spinach in Virginia. The material is cheaper than red copper oxide and less irritating to workers who treat seeds on a large scale.

Some striking contrasts between red copper oxide and zinc oxide as seed protectants have appeared. In the same lot of soil red copper oxide has given good results on peas, while zinc oxide has not (24). (See Fig. 6.) On the other hand, zinc oxide has given good results on cabbage, while red copper oxide has not. (See Fig. 7.) On spinach, tomato, or lettuce, results have been essentially the same with the two materials. Cook (10) and Ogilvie and Hickman (38) report a similar situation.

Cook has sought to explain the discrepancy. Assuming a differential action on the soil organisms, he mixed the two materials half and half and found no difference whether one or the other or both were used on spinach. He concluded that all the damping-off organisms involved seem to be controlled by either treatment. This result is not unexpected, however, since both materials are essentially equal on spinach. It would have been illuminating to have used the mixture

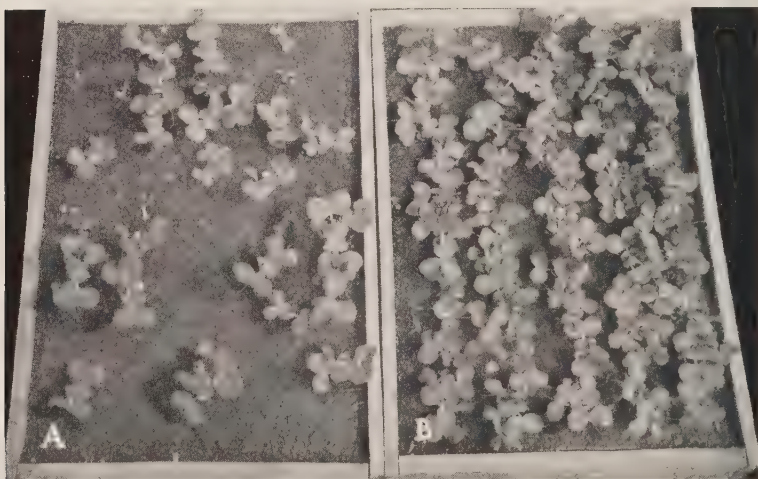


FIG. 6.—COMPARING PROTECTIVE VALUE OF ZINC OXIDE AND RED COPPER OXIDE ON PEA SEEDS.

Left, 100 seeds protected with zinc oxide; *right*, 100 seeds protected with red copper oxide.



FIG. 7.—COMPARING PROTECTIVE VALUE OF ZINC OXIDE AND RED COPPER OXIDE ON CABBAGE SEEDS.

Left, 1,000 seeds protected with zinc oxide; *right*, 1,000 seeds protected with red copper oxide.

of both on cabbage and peas as well, plants on which they exercise differential action.

Mixtures of copper carbonate plus Semesan and copper carbonate plus calomel have been tested at this Station (20) on tomato seed, but no differential action on the organisms was observed, altho copper carbonate seemed to reduce the calomel injury to tomato seeds.

It seems probable that part at least of the discrepancy may be due to differential injury. It is known, for instance, that copper and zinc oxides are both harmless to tomato seeds, that zinc oxide stunts peas but does not stunt cabbage, and that red copper oxide stunts cabbage but seldom stunts peas.

All of these data emphasize again the specificity of damping-off control and indicate that the problem may become more complex before it becomes simpler again.

ORGANIC MERCURIES

The organic mercury materials have been studied perhaps more over the world as seed protectants than any other group of substances. Clayton (6, 7) of this Station gave considerable attention to the adaptation of these materials on Long Island. In 1928 he showed that the best results from seed protection occurred in the early spring when seeds remained for long periods in the soil before they could emerge. In comparing Semesan dust with Semesan soak, he found an advantage for the soak. Benefit was obtained on cabbage, spinach, peas, string beans, cucumbers, tomatoes, and corn. Sometimes lettuce and radish were benefited, at other times they were injured.

In 1931 Clayton (7) showed that lima beans are very likely to be stunted by organic mercury. A similar effect was observed at this Station in 1937. The stunting effect lasts for the life of the plant. Semesan Jr. gave consistently good results on corn and is to be recommended. Dr. Crozier of this Station is conducting further tests on corn seed protectants. No satisfactory material was found for string beans after exhaustive tests. From the standpoint of injury Semesan soak was considerably less injurious to seeds of the cabbage family than dust. Semesan, in Clayton's tests, was superior to any of the following copper materials: Copper carbonate, copper tartrate, copper chloride, and copper acetate. He did not use red copper oxide.

Jones (31, 32) tested organic mercuries extensively on peas and concluded that Semesan was much the most effective of the lot, probably because it contains sufficient mercury to give protection at a dosage of material that will stick to the seeds. Semesan checked development of foot rot and basal-stem rot of peas caused by seed-borne *Ascochyta pinodella* and *Mycosphaerella pinodes*, but it did not affect the development of *Ascochyta pisi* on leaves and pods.

Semesan gave a larger measurable effect on seed of low vitality than on seed of high vitality; on sweet wrinkled varieties than on the Alaska variety of pea.

This is in line with the common observation on cabbage in western New York. This seed is commonly treated with hot water to control black leg and black rot. Such treatment tends to lower the vitality, which seems to be brought back somewhat by Semesan treatment.

THE NATURE OF SEED PROTECTION

Seed protection has evoked much interesting speculation as to its explanation. The protective action on the seed or the control of pre-

emergence damping-off is presumably quite simple. As one grower expressed it, "The seed is galvanized against decay" by the layer of fungicide surrounding it. That this is not a question of seed disinfection is easily proved (22 and 39) by sowing protected seeds in steamed soil from which the pathogenic organisms have been removed. Treatment shows no benefit if "healthy seeds" have been used.

The reduction in post-emergence damping-off by a seed protectant is not so simple. It is not easy to explain the reduction of disease at the soil line by a chemical on the seed which may have been planted $\frac{1}{2}$ inch or more below the surface. Two possibilities have presented themselves, (a) that treated seeds, while being pushed upward thru the soil, may leave behind sufficient chemical to kill parasites subsequently attempting to penetrate to the stem; or (b) that the seedling may absorb sufficient ionic copper to render it resistant to damping-off. Photographic evidence has been obtained (39) in the case of spinach for the first theory. Red copper oxide has been found along the stem of a spinach seedling growing from protected seed.

A depth of planting trial was designed to throw light on this question. If the rubbing-off hypothesis is sound, deep-planted seeds should show a smaller control of post-emergence disease than shallow-planted seed. Tomatoes dusted with anhydrous copper sulfate and red copper oxide were sown at $\frac{1}{2}$ -inch and $1\frac{1}{2}$ -inch depths. As shown in Table 3, control of post-emergence damping-off was just as good at $1\frac{1}{2}$ inches as at $\frac{1}{2}$ inch, indicating that the rubbing-off theory, if sound, will not cover the whole case.

TABLE 3.—EFFECT OF DEPTH OF SOWING ON SEED PROTECTIVE VALUE OF COPPER DUSTS ON TOMATO SEED.

TREATMENT	$\frac{1}{2}$ INCH DEEP			$1\frac{1}{2}$ INCH DEEP		
	Ave. No. emerged	Per-centage emerged	Per-centage post-emer-gence disease	Ave. No. emerged	Per-centage emerged	Per-centage post-emer-gence disease
None.....	1,194	79.6	51.5	1,066	71.0	48.0
Red copper oxide....	1,294	86.3	19.3	1,283	85.5	19.3
Copper sulfate dust...	1,307	87.1	21.5	1,318	87.9	20.0

The theory that the seedling may absorb sufficient ionic copper to render it resistant for a time is intriguing but difficult to attack experimentally. Data already published (22) comparing the soluble

copper monohydrate dust with the insoluble copper carbonate dust and the copper sulfate soak fit this theory. The soluble dust gave better post-emergence disease control than the insoluble dust, but less than the soak. The data just presented showing equal control of post-emergence disease $1\frac{1}{2}$ inches from the seed as $\frac{1}{2}$ inch from the seed also can be explained by the absorption of copper into the stem.

Seeds like the pea are not shoved out of the ground with the attendant sloughing of chemical, yet post-emergence disease is also reduced on this plant by seed protectants. The same is true of the corn seed (34). This may be due to absorption of copper or it may be due to the protective action of the chemical in delaying penetration of pathogens thru the seed, as discussed by Kadow and Anderson (33).

Effect of inoculum potential on protective value.—Seed protectants are commonly considered to give insurance against poor stands. They are applied by the grower with the expectation that he will not need them unless damping-off happens to be severe. He pays his premium and expects protection.

It is interesting to inquire as to how much protection he actually obtains and to determine how the protection obtained is related to the severity of disease. *Inoculum potential* has been defined essentially as the disease producing power of a soil (22). How then does protective value vary with inoculum potential?

To measure inoculum potential, it is only necessary to determine the number of non-protected seeds that are decayed by the disease. This can be determined by deducting the percentage of seedlings that emerge from the percentage of viable seeds in the stock.

The work on seed protection at this Station affords a huge pile of data useful for studying the relation of seed protection to inoculum potential. Curves have been plotted by inspection from all of the data available on the copper soak and dust on tomatoes, and on the red copper oxide dust on cucumber, eggplant, pea, and spinach, and tomato. Two typical curves are given in Fig. 5. The spinach curve (Fig. 8B) is given because spinach is so sensitive to damping-off. The pea curve (Fig. 8A) is given because the data for it were obtained in the greenhouse and climate laboratory at 15°C . The y axis of the curves is inoculum potential and the x axis is seed protective value (emergence of protected seeds). The points oscillate somewhat widely as might be expected because there are many variables in the experiments in addition to a large sampling error. There are 29 experiments for the pea curve, and 16 for the spinach curve. Curves plotted from other data resemble those illustrated.

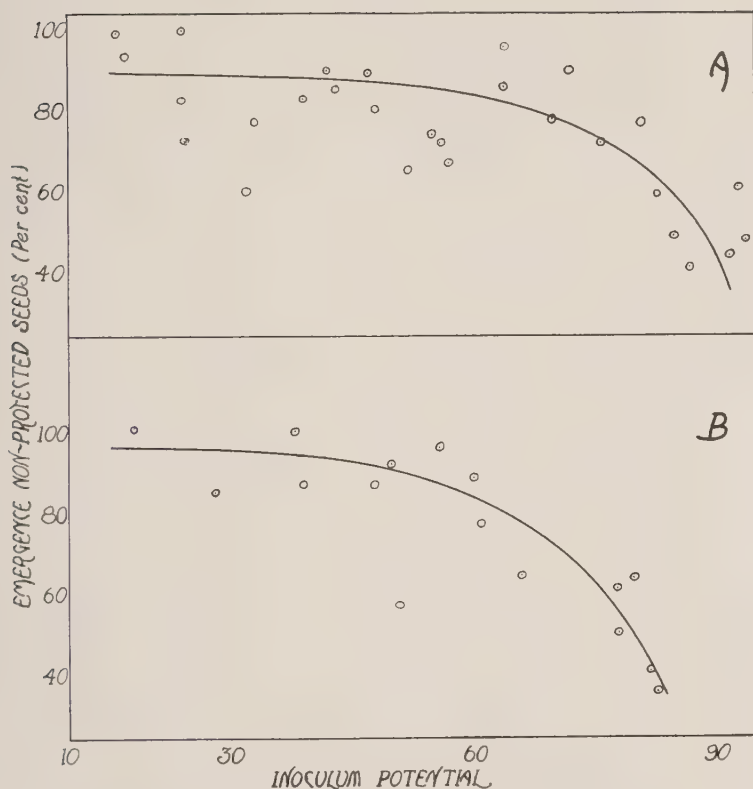


FIG. 8.—EFFECT OF INOCULUM POTENTIAL ON SEED PROTECTIVE VALUE OF RED COPPER OXIDE.

A, pea, $\frac{1}{4}\%$ red copper oxide, all varieties, climate laboratory 15° C. B, spinach, 2.5% red copper oxide, King of Denmark variety, greenhouse.

The position of the curves varies slightly, but the similarity of them all is striking. It is obvious, from a study of these curves, that the protective value of these copper materials varies with the inoculum potential, but the relation is not of a simple straight line order. In other words, the protective value does not decrease directly as the inoculum potential increases. All of the curves are J-shaped, breaking between 60 and 80 inoculum potential. That means in essence that the grower gets all the protection he pays for as long as his soil is not so heavily contaminated as to rot 80 per cent of non-protected seed. If the soil rots more than that, his protection diminishes rapidly.

RELATION OF DOSAGE TO SEED PROTECTION

Dosage is a phase of seed protection that is sometimes neglected. By its very nature a seed protectant must be neither very soluble nor very volatile if its effect is to last during the time period before sowing or during the time period when protection is required in the soil. If it is insoluble and non-volatile its sphere of activity is limited and hence it should cover completely the whole of the seed.

A certain minimum amount of protectant per unit area of seed surface should be required to give this coverage. This amount of material may be defined as the "minimum coverage dosage". This minimum coverage dosage is, of course, impossible to determine with precision because the dosage curve follows the curve of diminishing returns. It may be taken, however, as the point above which the curve is fairly flat.

Heretofore, these dosages have been calculated on the basis of weight of seed. Technically this may be expressed as percentage by weight. This method of calculating dosage is simple, quick, and easily understandable by the consumer of seed protectants.

The minimum coverage dosage of red copper oxide has been investigated for several seeds. The minimum coverage dosage is approximately 1.5 per cent by weight for spinach (10, 40), 0.25 per cent for cucumbers (26) and 0.5 per cent for peas (19).

Percentage-by-weight-dosages do not convey much information about the actual coverage of protectant over the seed surface. It is clear that the dosages vary from seed to seed, but it is equally clear that the size of the seeds varies also and that that would influence the seed surface exposed in unit weight.

Assuming that minimum coverage dosage per unit area of seed surface would be essentially equal for spinach and peas, it has been interesting to calculate the amount of red copper oxide per square centimeter of seed surface for the two seeds.

Weight data on seeds has been converted into surface data by assuming that each seed represents a sphere. Two methods were used in calculating surface area: (a) The two diameters of 10 spinach (Long Standing Bloomsdale) and 10 pea (Perfection) seeds were measured and averaged. The average number of seeds per 100 grams was determined from three samples; and (b) known numbers of seeds were immersed in water and the displacement noted. From these facts the surface area per 100 grams of seeds could be calculated and from

this figure could be calculated the amount of red copper oxide per square centimeter of seed surface for spinach and peas (Table 4).

TABLE 4.—CALCULATION OF AREA OF SEED SURFACE PER 100 GRAMS OF SEED AND DOSAGE OF RED COPPER OXIDE AND COPPER PER SQUARE CENTIMETER.

METHOD OF CALCU- LATION	SEED USED	RADIUS, MM	No. SEEDS PER 100 GRAMS	AREA, CM ² /100 GRAMS	MINIMUM COVERAGE DOSAGE		
					Per- centage by weight	Mg/cm ²	
						Red copper oxide	Metallic copper
Diameter	Spinach	1.51	9,660	2,768.6	1.5	0.542	0.461
Displace- ment	Spinach	1.33	9,660	2,147.9	1.5	0.698	0.593
Diameter	Pea	3.93	475	922.2	0.5	0.542	0.461
Displace- ment	Pea	3.61	475	778.1	0.5	0.643	0.547

The agreement between the figures for the coverage per square centimeter for the two seeds and for the two types of measurement is sufficiently close to indicate that the original assumption is correct, i.e., that the minimum coverage dosage is essentially a constant, irrespective of the type of seed. The data indicate further that the significant figure for dosage is weight of protectant per unit area of seed surface, not the percentage by weight of protectant.

Retention³ of dust is an important factor in testing seed protectants. Retention is a resultant of (1) the nature of the seed surface and (2) the nature of the seed protectant. A hairy seed like the tomato will retain more dust than a smooth seed like the pea or cucumber. Red copper oxide for example will be retained in larger quantity by any seed than many other copper materials.

One reason why cupric oxide is not as good a seed protectant as cuprous oxide (23) is that its retention on seeds is poor, although it has been shown recently to be low in fungicidal value as well (28). Kadow and Anderson (33) increased the retention of cupric oxide and its protective value by applying it to moistened seeds.

In doing experimental work it is easy to use excess dosages and screen off the material that is not retained. This was done in the early work at this Station (22, 23). This technic flatters the material under

³Retention is a term applied by Fajans and Martin (13) to denote the initial deposit of protective fungicides on surfaces.

test, however. There is a particle size population in any sample of dust material. When used in excess, the small particles are retained on the seeds. Those are the most fungicidal particles as shown by Heuberger and Horsfall (19). The large particles with low activity are screened off. Hence the minimum coverage dosage is higher for a material with large particles than for one with small particles.

Percentage of active agent (copper or mercury, for instance) in a compound is also important in seed protectants. When this percentage is low, more total material is required to give the minimum coverage dosage of the active agent than when the percentage is high. To give the necessary 0.5 mg (in round numbers) of copper per square centimeter on peas, it requires 0.5 per cent by weight of 85 per cent red copper oxide. It would require 2.5 per cent by weight of a compound containing 15 per cent copper. Peas will not retain 2.5 per cent, by weight of any copper compound and hence the copper compound in question would not be as suitable as red copper oxide as a seed protectant. This conclusion has been verified experimentally.

Jones (32) approached this problem of concentration of active agent in mercury seed protectants by applying them all at 3 ounces per bushel on peas. This is a dosage of 0.31 per cent by weight. He found that these materials were inefficient as seed protectants if they carried less than 6 per cent of organic mercury.

Friction of Dusted Seed

In the early work here on seed protection, especially with peas, results in the field did not agree with those in the greenhouse. This was found to be due (3) to an increase in the interfacial friction between dusted seeds. In the common type of grain drill, used for sowing peas, the seeds are forced thru a narrow throat. The interfacial friction set up by the dust increases greatly the drilling friction.

The increase in drilling friction had other results than to produce simple differences in seeding rate. The increased friction caused cracking of the pea (3) and cabbage (10) seed, and, at times, damage to drills. Such damage has been observed also on grain drills sowing wheat seed dusted with copper carbonate (17).

A study of the effect of dusts on the flow of vegetable seeds thru the gravity type seeder was made recently by Pearson (39) who showed that red copper oxide and zinc oxide reduced the gravity flow of smooth seeds but accelerated the flow of rough seeds like the beet. It is interesting that one of the first farmers in New York State to sow

dusted beet seeds reported that they flowed more smoothly than non-dusted seeds.

To prevent cracking of both seeds and drills it is desirable to include finely pulverized graphite with the treatment, using half as much graphite as seed protectant. This has become standard practice for peas (3) and is now recommended for cabbage by Cook (10).

It has sometimes been said that organic mercury dusts do not increase interfacial friction between seeds, but canners report drill trouble when Semesan has been used on pea seeds. Tests on the subject have shown that organic mercuries increase interfacial friction almost as much as red copper oxide when used at equivalent dosages.

A new method of measuring interfacial friction has been devised recently (42). To use a drill cup is slow and cumbersome and does not give a true picture of the drilling friction encountered. The new method consists in filling a tall form 300-cc beaker with 10 ounces of pea seed and placing it on a tared spring balance of 25-pound capacity. A piece of 1½-inch wooden dowelling, flat on the end, is thrust 3 inches into this seed. The pressure in pounds necessary to make the thrust is shown on the dial of the balance and recorded by an assistant. Typical data from Suit and Horsfall (42) obtained with this method showing the effect of various materials and various graphites on interfacial friction appear in Table 5.

THE RÔLE OF SOIL TREATMENTS

Since the organisms known to cause damping-off are soil residents, the earliest work on damping-off control was devoted to killing these organisms by heat.

PASTEURIZATION

Steaming.—Various methods of applying the heat have been devised. Sometimes the soil is baked in pans over a fire; sometimes it is placed in pressure cookers of one sort or another; and sometimes it is steamed in the beds or benches by (a) permitting the steam to escape into the soil from buried tiles, or (b) by introducing it into the soil thru a series of pipes called a "rake." No research has been done at this Station on soil steaming, but this subject is well discussed in Cornell University Extension Bulletin No. 217.

Hot water drench.—This is an old old method for heating soil and is well adapted to the home gardener with a few boxes of seedlings to start off. A 5-minute immersion of small pots or boxes in boiling

TABLE 5.—EFFECT OF VARIOUS MATERIALS ON THE INTERFACIAL FRICTION OF DUSTED SEEDS.

MATERIAL	LUBRICANT*	PEA SEED						WHEAT		BEET SEED	
		Dosage, per cent by weight	Friction†				Alaska	Forward		Dosage, per cent by weight	Friction †
			Wisconsin Early Sweet	Wilt resistant Perfection, with moisture content of		Dosage, per cent by weight		Friction †			
				8/5/37	9/19/37				12%			8.8%
Check.....	.....	....	2.92	2.98	6.81	5.93	3.12	....	1.31	....	9.49
Red Copper Oxide	.....	0.25	7.83	8.79	22.10	11.60	6.57	0.21	4.80	2.0	11.10
Red Copper Oxide	Dixon Graphite No. 0607, flake	0.25	3.58	3.80	5.79	....	3.69	0.21	2.23	2.0	10.20
Red Copper Oxide	Pacific Graphite No. 85, amorphous	0.25	....	....	8.15	....	....	....	....	....	....
Red Copper Oxide	Pettinos Graphite No. 98, flake	0.25	....	....	6.85	5.51	....	....	....	....	....
Red Copper Oxide	Acheson Graphite No. AF1, amorphous	0.25	....	....	7.56	....	....	....	....	....	....
Red Copper Oxide	Superior Graphite No. X10, amorphous	0.25	....	....	9.22	6.78	....	....	....	....	....
Red Copper Oxide	Whiting	0.25	....	....	16.00	12.00	6.83	....	....	....	....
2% Ceresan	Dixon Graphite	0.25	7.53	....	....	....	6.22	....	....	....	....
2% Ceresan	No. 0607, flake	0.25	....	....	....	....	4.70	....	....	....	....
New Improved Ceresan	.....	0.05	4.83	....	8.19	....	....	0.042	1.90	....	....
New Improved Ceresan	.....	0.10	....	....	10.40	....	....	....	....	....	....
New Improved Ceresan	.....	0.25	....	....	11.50	....	....	....	....	....	....
New Improved Ceresan	.....	0.40	....	....	13.10	....	....	....	....	....	....
Copper Carbonate	.....	....	....	....	....	....	....	0.21	6.81	....	....
Semenan	.....	....	....	....	....	....	....	....	....	2.0	12.40
Zinc oxide.....	.....	....	....	....	....	....	....	....	....	2.0	16.30
Talc	.....	0.25	....	....	....	....	5.78	0.21	2.47	2.0	14.00

water is sufficient. Boiling water applications on a larger scale seldom pay, however.

Electric heat.—The use of an electrical soil pasteurizer has been studied at this Station (25) and at the Cornell Experiment Station (36) as a means of killing damping-off organisms in soil. The method generally is expensive and laborious. The expense can be materially reduced by giving attention to the temperature obtained and by the design of the heating chamber.

The tendency in all soil cooking processes has been to heat soil too hot. Boiling water temperature has been aimed at, presumably on account of the tendency to think of steam temperatures. As a result of the high temperature the physical qualities of the soil are adversely affected. Plants do not grow well for a time in overcooked soil. Overcooked soil no longer holds water as well as before. A voluminous literature has been developed to explain the effect.

A study of electric heat has served to demonstrate that soil need no longer be overheated. This is perhaps the significant advance resulting from the research. Machinery for applying electric heat for maximum effect and at minimum cost is still very poorly designed, however. It should be emphasized that efficiency in low temperature cooking to get maximum effect with minimum cost will be attained by efficiency in applying the heat. Electric heat offers possibilities in this respect.

In the present electric pasteurizers the heating elements are distributed thru the mass of soil, but even the best arrangement suffices only to mix the heat with the soil, not the soil with the heat. As a result, soil next to the heaters becomes overheated, while that between the heaters, in the corners, and on the bottom is underheated. An outfit needs to be designed for moving the soil past the heaters, that is mix the soil with the heat. A rotating mixer is perhaps the most desirable for the purpose. By this principle the heaters need not become too hot and overcook the soil, and the soil can all be heated to the desired temperature quickly without waste of electricity.

From a knowledge of the death points of damping-off organisms, it is probable that 55°C (129°F) for an hour would be sufficient, provided all the soil could be heated uniformly.

Pending such developments, it is perhaps wisest to bring the coldest point in a pasteurizer to 55° C and then turn off the current, permitting the "fireless cooker" effect to proceed.

Hot water pipes.—Since electric heat is expensive, at best it seems worthwhile to try hot water pipes instead of electric heaters. This has been done experimentally.

In one commercial application pipes were laid in the bottom of a bench and heated with hot water from a coil in the furnace. Satisfactory pasteurization was obtained keeping the soil at 55° C for 3 hours. This type of pasteurization, altho not as flexible as the use of electric heat, nevertheless, warrants further work because it is much cheaper.

FORMALDEHYDE

Formaldehyde gas possesses many advantages as a soil treatment and many methods of application have been devised. Its chief advantage, aside from its toxicity, is its penetrating powers.

Originally, formaldehyde was used as a drench adding from $\frac{1}{2}$ to $1\frac{1}{2}$ gallons of a 1 to 50 dilution per square foot. Such procedure tended to puddle the soil, made it inactive for at least 10 days while the formaldehyde escaped, and was tedious and expensive.

An advance was made when Alexander, Young, and Kiger (1) discovered that a 6 per cent formaldehyde dust applied about $1\frac{1}{2}$ ounces per square foot worked well, possibly because the gas penetrates dry soil better than waterlogged soil. Using this method it was possible to sow seeds within 24 or 36 hours and thus reduce the waiting time.

Guterman and Massey (18) decided that the dust was not necessary. They accomplished the same results cheaper by adding the requisite amount of formalin in a little water. It is now suggested that $2\frac{1}{2}$ tablespoonfuls of 40 per cent formaldehyde be mixed with each bushel of soil or 1 tablespoonful per flat. This should be diluted with 5 or 6 parts of water and mixed thoroly into the soil which should stand 12 to 24 hours before seeding.

The possibility of combining formaldehyde and steam has been realized by Beachley (4) in Pennsylvania who has devised a machine to vaporize steam and formaldehyde together and apply them to the soil under a steam pan. Beachley used 1 pound of formalin per 100 square feet and found that the treatment cost about 80 cents per 100 square feet as compared with about \$1.00 per 100 square feet for steam alone. The saving comes from an economy of time and labor, but the first cost of equipment is high as with most pasteurizing machinery.

SAND CULTURE

Dunlap (12) has attempted to solve the damping-off problem by growing his plants in sand containing none of the damping-off organisms. Using common builders sand, he washes it in water at 160° F until free of dirt, then places it in clean flats and sows the seed un-

treated. The sand is then watered with a weak solution of saltpeter ($\frac{1}{2}$ teaspoonful per pint of water per square foot of sand) to give the seedlings a little plant food. Seedlings are watered as required with clean water, taking care not to get the sand contaminated with damping-off soil. This method definitely has possibilities especially for home gardeners interested in producing clean seedlings.

ZINC OXIDE

A disadvantage common to all the soil treatments previously discussed is that the killing agent functions and then disappears leaving no residue to guard against recontamination. It is a common experience in the greenhouse that soil once freed of organisms by say steam or formaldehyde will show more damping-off if the fungus gets back in than if it had not been treated at all.

The object of most of the damping-off research at this Station has been to find suitable lasting chemicals for the purpose. Red copper oxide (23) and zinc oxide (24) as seed protectants do that for the seeds. Zinc oxide spread over the surface of the soil before the seedlings emerge at the rate of $\frac{1}{2}$ ounce per square foot served to prevent post-emergence damping-off. This material being insoluble, however, will not penetrate deeply enough into the soil to prevent pre-emergence damping-off and hence should never be used without a seed protectant. This material gained rapidly in favor at first despite some injury to seedlings but has lately been superseded by the red copper oxide spray which gives the same results without the injury. The treatment still finds a place with growers where zinc is not injurious.

RED COPPER OXIDE SPRAY AND DIP

In the greenhouse red copper oxide was tested as a foliage dust as early as 1932 (23) and as a spray in 1934 (27) when it was discovered to be less injurious than bordeaux mixture to plants like the tomato. This difference has lately been shown to be due to the lime in bordeaux mixture (29) which injures many sorts of plants.

Red copper oxide was first tested as a seedling spray in 1934. As shown in Table 6 it gave a marked reduction in post-emergence damping-off.

The spray was reported from two counties of the State as effective against post-emergence damping-off of celery.

Damping-off of new transplants is sometimes a serious factor in New York greenhouses. If red copper oxide is applied so as to cover

TABLE 6.—EFFECT OF RED COPPER OXIDE SPRAY ON CONTROL OF POST-EMERGENCE DAMPING-OFF OF SPINACH IN GREENHOUSE.

TREATMENT	TOTAL EMERGENCE	POST-EMERGENCE DAMPING-OFF, PER CENT
No treatment.....	155	64.5
Red copper oxide on seed.....	450	41.8
Red copper oxide on seed, zinc oxide on soil	451	29.7
Red copper oxide on seed, red copper oxide spray.....	476	16.6

the stems of the seedlings, these will be protected when they are transplanted. In one experiment, for instance, non-sprayed seedlings damped-off 58 per cent, whereas, sprayed seedlings damped-off only 22 per cent.

The important consideration in using red copper oxide spray is to be sure that the spray covers the entire stem and runs down into the soil. It is difficult to persuade the spray to penetrate thru the crown of leaves to the stems. The best method apparently is to withhold water until the plants wilt slightly, then spray heavily. As soon as the spray dries, the plants can be watered again. It is usually recommended to spray at weekly intervals, being sure to spray just as the plants prick thru the ground and just before transplanting.

Lately the treatment is being applied extensively in the State on a wide variety of seedlings. As yet few reports have come in as to injury, altho the material may stunt seedlings of cabbage, cauliflower, broccoli, brussels sprouts, clarkia, and petunia.

In cases of especially stubborn damping-off, it has been worth while to dip seedlings in the copper oxide suspension at transplanting time.

In the field, damping-off is frequently as severe as in the greenhouse, and when it is, it is more serious to the grower. Seed protectants constitute the first line of defense against the disease in the field. Damping-off of beets gave a chance to test the red copper oxide spray in 1937. Damping-off had wiped out the first two plantings. The third planting was sprayed just as the seedlings emerged, using one "jumbo" nozzle per row held close to the plants. A boom sprayed six rows at a time using 150 gallons per acre of red copper oxide suspension prepared with 1 pound in 50 gallons of water.

Only one application could be made July 16 on account of press of other work, but even this single spray gave reduction in post-emergence

damping-off. Counts on July 24 and August 20 of number of living seedlings were made in ten 10-foot row sections. The results are shown in Table 7.

TABLE 7.—EFFECT OF RED COPPER OXIDE SPRAY ON CONTROL OF POST-EMERGENCE DAMPING-OFF OF BEETS IN THE FIELD.

TREATMENT	AVERAGE NO. OF PLANTS IN TEN 10-FOOT SECTIONS OF ROW	
	July 24	Aug. 20
No treatment.....	605	488
Cuprocide 54*.....	780	599
Cuprocide.....	653	596

*Cuprocide 54 is specially milled red copper oxide.

Altho these data are not extensive, they show the same trend as that observed in the greenhouse and, therefore, give definite promise that field damping-off can be combated by spraying. More work on this subject is contemplated.

The question has arisen and considered somewhat by Kadow and Anderson (33) as to using bordeaux for a seedling spray. Doubtless bordeaux would be effective. In fact it has been recommended for a long time but never really adopted by growers. The lime in bordeaux stunts seedlings badly (29), and that is why bordeaux has never been used widely to protect seedlings. Red copper oxide spray contains no lime and, hence, does not stunt seedlings. For that reason New York farmers prefer it. Recently copper oxychloride is being used as a seedling spray also.

CHEMICAL DRIPS IN THE FIELD

While searching for a method of decreasing the field losses of pea stands, the drip method of applying chemicals presented itself. This method was evolved for the control of onion smut (41), which, like damping-off, attacks very young seedlings. The method simply consists of dribbling the chemical in water from a tank attached to the seeder. The tank used discharged about 1 gallon of material per 150 feet of row.

Data during 4 years on peas in the field, given in Table 8, show remarkable responses from 1-150 formalin as well as from 1 per cent and 0.5 per cent copper sulfate. Acetic acid and zinc sulfate were injurious. The injuriousness of zinc sulfate is in line with the injuriousness of zinc oxide as a pea seed protectant already illustrated (24).

Another interesting point in Table 8 is that water alone dribbled on the seeds reduced the stand. This gives the same effect as a rain immediately after seeding, as reported by Jones (32) and as discussed above (page 13).

TABLE 8.—EFFECT OF CHEMICAL DRIPS ON EMERGENCE OF PEAS IN THE FIELD

TREATMENT	AVERAGE EMERGENCE PER 10 FEET OF ROW			
	Alaska 1930	Alaska 1931	Telephone 1932	Perfection 1938
Non-treated dry.....	...	21.2	18.6	18.5
Water.....	26.0	16.2	11.5	19.2
3% acetic acid.....	17.0	...	...	...
2% acetic acid.....	30.7	11.0	...	...
1% acetic acid.....	...	10.2	20.9	...
3% copper sulfate.....	29.0	...	...	...
2% copper sulfate.....	30.6	...	...	...
1% copper sulfate.....	...	...	24.3	19.6
0.5% copper sulfate.....	...	24.4	...	...
1% zinc sulfate.....	...	...	13.2	...
1-50 formalin.....	21.1	...	...	...
1-100 formalin.....	35.2	29.2	17.1	9.3
1-150 formalin.....	34.2	32.0	23.1	...
Red copper oxide, 1 lb. to 50 gals.	...	...	...	22.5

A test of the drip method of combating damping-off was tried in the greenhouse using beets drilled on a greenhouse bench. The data given in Table 9 show that red copper oxide seed treatment gave the best stand, followed by 1-150 formalin drip, and zinc oxide seed protectant. The copper sulfate drip was inferior in this test. Here again, as with peas in the field, a water drip reduced the stand.

TABLE 9.—COMPARING FORMALIN AND COPPER SULFATE DRIP WITH RED COPPER OXIDE AND ZINC OXIDE SEED PROTECTANTS FOR DAMPING-OFF CONTROL OF BEETS ON THE GREENHOUSE BENCH.

TREATMENT	AVERAGE NO. SEEDLINGS EMERGED, 3 REPLICATIONS	DAMPED-OFF, %
Non-treated, dry.....	67.7	13.3
Non-treated, water drip.....	61.7	22.4
1% acetic acid, drip.....	61.0	12.2
1% copper sulfate drip.....	73.3	3.7
Zinc oxide seed protectant.....	115.7	4.5
1-150 formalin drip.....	157.0	1.5
Red copper oxide seed protectant.....	192.0	1.0

A L. Harrison, formerly of this Station, made an independent experiment in 1932 on this method of damping-off control. This has been

published (40). Formaldehyde drip controlled both pre-emergence and post-emergence disease better than such seed protectants as mercuries or copper sulfate monohydrate dusts.

MISCELLANEOUS SOIL TREATING MATERIALS

During the search for a control of damping-off, a large number of materials have passed in review, but only a very few have ever shown real promise. Most of these have already been discussed. The others that have promise but which are neglected for one reason or another will be discussed here.

Mercury compounds.—The high toxicity of mercury for fungi makes it an ever-present possibility in damping-off control, but it is such a two-edged tool cutting both plant and fungus that its possibilities are not yet fully realized. Corrosive sublimate filled a big need, but it is gradually being replaced. The use of this material for damping-off control was discovered at this Station by Gloyer and Glasgow (16) when they were working on the control of cabbage maggot. Even yet this is probably the best method currently used for controlling post-emergence damping-off and wirestem on cabbage. Cabbage growers are using it at the rate of 1 ounce to 10 gallons of water dribbling it along the row of seedlings with a tank mounted on wheels. Several applications may be required for best damping-off control.

Recently, Glasgow (15) has improved the corrosive sublimate drip for cabbage maggot by substituting seed protection with calomel, which also gives protection against pre-emergence and post-emergence damping-off as well.

Altho the cabbage family is not sensitive to mercury poisoning, most other plants show too much injury from corrosive sublimate and calomel to be safely treated except in certain localities where the mercury is known not to be very injurious to the seedlings. In any case the material should not be allowed to touch leaves.

Organic mercury drench (Semesan) has long been used for damping-off control on seedlings. Since the mercury is bound up more tightly in Semesan than in corrosive sublimate, it is safer on more plants than cabbage, but it does seem more injurious than desirable to many plants, especially tomatoes.

Potassium permanganate.—Used at the rate of 1 ounce to 4 gallons this material has also long been employed more or less by practical growers for combating damping-off. It is watered onto the soil or used as a dip for cuttings. Tests at this Station indicate that it pos-

sesses distinct fungicidal value, but its effects are too fleeting. Treated plants damp-off later. Red copper oxide spray or the zinc oxide soil treatment are both more efficient. Assuming that this action may have been due to oxidation, extensive trials with potassium dichromate have been conducted. It has given much better control than potassium permanganate, but has always been too injurious for commercial use. The material has shown such promise, however, that additional work with it needs doing.

Sulfuric acid.—This seems to have a distinct place in combating damping-off of forest seedlings where 1 ounce is used to cover from 3 to 5 square feet of bed space, depending upon the soil. The use of sulfuric acid may be very injurious, however, probably so much so as to be out of the question for use on most vegetable and flower seedlings.

Aluminum sulfate.—Tested extensively by Wiant (43) on coniferous seedlings, this material showed very promising results when used at a rate between 16 and 20 pounds per 1,000 square feet and when applied either dry and watered in or in solution, in one trial at this Station. Non-treated tomatoes germinated 70.3 per cent; those where aluminum sulfate was applied at planting at the rate of 35 pounds per 1,000 square feet germinated 79.3 per cent. Post-emergence disease in this test was determined not from the number damped-off, but from the number of seedlings with spots on their roots. The percentages were 43.5 for non-treated plants, 3.4 for aluminum sulfate-treated plants.

These figures indicate that aluminum sulfate has promise but needs more testing on vegetables.

Chlorine.—Chlorine has occasionally been suggested for damping-off control. At this Station it has been tested by means of hypochlorites (Chlorox and Zonite), at dilutions of 1, 10, 50, and 100 to 1,000 without appreciable effect on either pre-emergence or post-emergence damping-off of tomatoes. It was injurious at 1-1,000.

Sulfur.—Sulfur materials have been extensively tested by others but not found effective for damping-off. Tests at this Station have included calcium monosulfide, sulsol, sulfocide, elemental sulfur, and a so-called colloidal sulfur at 20 grams per square foot. None controlled either phase of damping-off on tomatoes and all stunted the seedlings somewhat.

Dyes.—Dyes were tested briefly. Methylene blue $1-10^2$, $1-10^3$, $1-10^4$, and $1-10^5$ were worthless as soil treatments.

Charcoal.—Chupp (8) raised the question more than a decade ago as to whether charcoal possessed any damping-off control value. Extensive tests at this Station indicated that it had little or none.

Wood ashes.—One of the greenhouse laborers insisted upon trying wood ashes as a soil treatment. Interestingly enough, they did reduce damping-off of spinach slightly in three separate tests as shown in Table 10. There also seemed to be a slight reduction in disease from lime, soda, and gypsum, but in no case did the disease control approach that obtained with the combination of red copper oxide on the seed and zinc oxide on the surface of the soil.

Buchholz (5) showed a reduction of damping-off of alfalfa with decreasing acidity, a possible explanation for the results with lime, soda and wood ashes.

As this manuscript goes to press, a bulletin on damping-off by W. L. Doran arrives.⁴ This bulletin deals exclusively with soil treatments for damping-off of ornamentals. The writer concludes that the following materials were relatively ineffective under his conditions: Lime, gypsum, calcium chloride, calcium acetate, calcium hypochlorite, tannic acid, potassium permanganate, charcoal, and ammonium thiocyanate. On the other hand, he finds uses for washed sand, calcium cyanamide, ammonia, formic acid, formaldehyde, acetaldehyde, salicylic acid, acetic acid, pyroligneous acid, copper-lime dust and aluminum sulfate. The writer would have found it advantageous to combine a seed protectant with some of these materials. It is unfortunate that he should speak of the effect of the chemicals on seed germination instead of seedling emergence. The treatments used aid emergence, not germination. They are as effective on highly viable seeds as on any others.

RELATION OF CULTURAL PRACTICES TO DAMPING-OFF

CLEANLINESS

"Cleanliness is next to godliness", goes the old saw. Cleanliness is of paramount importance in damping-off control. Chemicals on seed, soil, or seedlings will do their share. Steaming, pasteurization, drenching have their place in a control program, but none of these practices can take the place of care for the plants.

⁴Massachusetts Agr. Exp. Sta. Bul. No. 351.

At least once a year all plants should be removed from the greenhouse. The benches, beds, sash bars, and floors should be sprayed with formaldehyde or at least with 1 per cent bluestone water. The house and all its surroundings should be thoroly overhauled, cleaned, and painted with gloss paint.

Diseased plants, if they occur, should not be thrown out on the compost pile or under the bench. They should be thrown into the furnace or carted away with the garbage.

THE COMPOST PILE

The compost pile is anathema to a plant doctor. It is probable that more damping-off is traceable to the compost pile than to any other source. Many compost piles sooner or later receive most of the refuse from the greenhouse, seedling soil, diseased plants, toppings, sweepings, and what not. Using the soil from such a pile is dangerous and unsanitary. The chickens or the pigs would never be fed their own refuse. Why should seedlings?

Every greenhouse operator knows that he should not put contaminated soil and sick plants on his compost pile, but many do it, a little surreptitiously perhaps, but do it nevertheless, because that is an easy way to get rid of it.

The use of manure in the compost is another source of damping-off germs. The best practice is to avoid it and substitute peat moss in the compost—if a compost pile must be made.

LIGHT

Light is woefully lacking in most greenhouses. Light is essential for best seedling growth. All growers know that damping-off occurs in dark weather and they hope that nature will provide them with bright weather. Some growers defeat their own ends, however, by having dirty glass, dark unpainted sash bars and other woodwork. Some put all sorts of shelves for plants on the greenhouse supports and shade plants below. Lean-to greenhouses are made without north light and cloth is used instead of glass over cold frames. Sash houses are built that show mostly wood and little glass. Attention to all of these points would help in disease control. Some of the most advanced greenhouse men are painting all possible surfaces except glass with aluminum paint which has a much higher reflecting power for light than does white paint.

TABLE 10. — EFFECT OF WOOD ASHES, LIME, GYPSUM, AND SODA ON DAMPING-OFF OF SPINACH; 10 GRAMS OR APPROXIMATELY 1,000 SEEDS SOWN PER FLAT.

TREATMENT	HOW APPLIED	SPINACH, OCT. 23, 1934		SPINACH, OCT. 6, 1934		SPINACH, DEC. 4, 1934	
		Emergence %,	Damping- off, %	Emergence %,	Damping- off, %	Emergence %,	Damping- off, %
No treatment.....	.....	25.8	20.6	32.9	28.2	33.8	68.8
Wood ashes.....	50 grams entire flat.....	39.4	14.5	.....	.....	.....	.....
Wood ashes.....	50 grams mixed surface.....	50.8	7.0	56.8	8.3	40.7	35.5
Wood ashes.....	50 grams applied to surface.....	23.3	15.3	53.5	13.8	.....	.....
Lime.....	50 grams mixed surface.....	62.6	6.0	.....	.....	42.7	32.7
Sodium bicarbonate.....	5 grams mixed surface.....	.....	.....	.....	.....	43.6	41.4
Gypsum.....	50 grams mixed surface.....	35.7	10.3	.....	.....	33.5	48.9
Wood ashes on seed.....	.....	23.3	18.8	.....	.....	.....	.....
Red copper oxide on seed.....	20 grams zinc oxide on surface.....	.....	.....	71.1	0.6	83.3	1.0

VENTILATION

Air circulation is of more importance in disease control than is commonly considered. It is poor practice to have low greenhouses or sash beds. Air drainage around the house itself and around the cold frames is desirable in disease control, altho more heat is required.

Heat is sometimes neglected. In severe cases of damping-off or when conditions are too dark and wet, it is preferable to ventilate the houses and add heat than to keep them closed and save on heat.

PRACTICAL CONSIDERATIONS

It is well to summarize the practical aspects of the work reported in this bulletin, altho it must be recognized at the same time that practical recommendations cannot always stand unqualified. The suggestions are given here, but the qualifications discussed in the main body of the paper cannot be ignored.

SEED PROTECTION

1. Seed protection is the simplest and cheapest method of damping-off control. It is the best field practice available. Being so, it should be used irrespective of almost any other method also used.

2. There are three great groups of seed protectants, *viz.*, copper, mercury, zinc. Of these three, copper, especially red copper oxide, is the most widely accepted. The list of plants that may be treated satisfactorily is given on page 9 and those that may be injured on pages 9-10. The plants benefited and injured by mercury are given on page 20. Those benefited and injured by zinc are given on page 17. Those plants not satisfactorily treated at all are given on page 18.

3. There are isolated cases of damping-off that are due to seed-borne germs that may be eliminated by seed disinfection, as listed on page 7. Seed disinfection for the control of damping-off, of course, must not be confused with seed disinfection for the control of other diseases, such as wheat smut, cabbage black-leg and black-rot, celery blight, etc. These diseases are outside the scope of this paper.

SOIL PROTECTION

4. Soil treatment as generally practiced has one or more of the following difficulties: It is expensive, cumbersome, injurious to plants, liable to recontamination. Nevertheless, it is widely used and is gaining in favor. It has the general advantage over seed protection of being more effective.

5. Pasteurization of one type or another is the oldest and most efficient, but the most expensive and cumbersome, of the soil treatments.

6. The hot water drench is a satisfactory treatment for small quantities of soil — using a 5-minute immersion of the soil containers in boiling water.

7. Pasteurizing soil with electric heat in conduits or hot water in pipes is gaining in favor, but the cost of current with the one and the cost of installation with the other works against its adoption.

8. Steaming is still much the most widely used of pasteurizing technics. It is a complicated method the details of which are discussed in Cornell University Extension Bulletin No. 217.

9. Formaldehyde drench has been outmoded by the newer dust and sprinkle types of application, both of which rose rapidly in favor for a time. Both are simple, relatively cheap, but tend to be injurious in certain soils or in a greenhouse where other living plants grow. The dust is currently used at $1\frac{1}{2}$ ounces per square foot worked into the soil a day or so ahead of using. The sprinkle method is much the same except that $\frac{1}{2}$ tablespoonful is applied in a little water to each square foot.

10. Combining formaldehyde and steam is a very new development with considerable promise for large areas. Those interested are referred to Pennsylvania Agricultural Experiment Station Bulletin No. 348, published within the past year.

11. The sand culture technic developed in Connecticut has definite promise but has not been used in New York as yet. It is fairly simple and inexpensive. It involves a hot water drench of the sand, flushing it with water at 160° F until clean. Seedlings are planted and watered with a weak solution of saltpeter ($\frac{1}{2}$ tablespoon per pint of water) per square foot of sand. This should be well adapted to the small gardener.

12. The zinc oxide treatment for the surface of the soil, $\frac{1}{2}$ ounce per square foot, used in addition to seed protection had considerable usage for a time because it gave long-time protection. This is not provided by most other soil treatments which depend upon agents like steam or formaldehyde that are dissipated. This is a relatively cheap method and quite simple, but its range is limited to certain soils which the grower can ascertain for himself. This method also is adapted to the home gardener.

13. The red copper oxide spray recently developed has tended to supplant the zinc oxide treatment. It is simple, cheap, and non-injurious to almost all plants except the cabbage family and some growers use it on that. This spray treatment, like the zinc oxide treatment, must be used in addition to a seed protectant. It will not give adequate control of post-emergence damping-off unless pre-emergence control is obtained with seed protection. The usual strength is 1 ounce of straight red copper oxide to 3 gallons of water. New formulas prepared especially for this purpose are now on the market. These are more readily suspendible in water, however, and hence are more satisfactory for use in hand sprayers.

To be effective this spray should be applied heavily, being sure that it runs down the stem into the soil. This is best done by permitting the leaves to wilt and droop slightly, so that the spray can be forced down thru the crown of leaves. Probably sprinkling-pot applications are not as satisfactory as drenching sprays.

This spray promises to be valuable for field damping-off of such crops as spinach and beets, altho this phase is still in the experimental stage.

14. Chemical drips in the row show distinct promise especially in the field. Startling differences in stand have been obtained on spinach and peas by dribbling 1-100 formalin or 1 per cent copper sulfate onto the seed as it was being sown. The corrosive sublimate drip for cabbage maggot at the rate of 1 ounce to 10 gallons also gives good damping-off control.

15. A series of miscellaneous materials have been used with more or less success as soil fungicides. Semesan drench used according to the manufacturers' advice is perhaps the most widely used of these.

SUMMARY

This paper is an effort to summarize the available information on damping-off, especially those phases that have been under investigation at this Station.

The nature of damping-off, its symptoms, and its causes are discussed. A damping-off-like symptom wherein plants shrivel and die is discussed as a probable result of excessive concentration of soluble salts in the soil. This is to be controlled, obviously, by leaching out the salts.

Two fundamental aspects of damping-off control are seed protection—protecting seeds and tiny seedlings from decay with seed dusts or dips—and soil treatment.

The protective value of seed dressings varies with the inoculum potential of the soil, altho the relation is not of a straight-line order. In other words, as the seed-decaying ability of a soil increases the protective effect of the copper declines, but the decline is unimportant until the inoculum potential reaches about 80 per cent of maximum. Above that the protective effect falls rapidly.

Two theories for seed protective effect are discussed, *viz.*, that the active agent in the seed diffuses into the soil and discourages penetration of disease organisms, and that the seedling absorbs sufficient copper to render itself less susceptible to attack.

The relative value of pasteurization of soil with hot water drench, steam, electricity, and hot water in pipes is discussed.

Formaldehyde and methods for its application, sand culture, zinc oxide, and miscellaneous soil treatments are discussed. The suggestion is made that chemicals may be dribbled along the row in the field to discourage entrance of damping-off organisms.

A new red copper oxide spray for damping-off is proposed and practical results given.

Finally a practical discussion is given to summarize the control measures.

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